Module 3 Forces & Motion

Unit 4 Materials

3.4 Materials

This section examines the physical properties of springs and materials.

Learners can carry out a range of experimental work to enhance their knowledge and skills, including the management of risks and analysis of data to provide evidence for relationships between physical quantities. There are opportunities to consider the selection of appropriate materials for practical applications (HSW5, 6, 8, 9, 12).

Module 2 – Foundations of physics

2.1 Physical quantities and units
2.2 Making measurements and analysing data
2.3 Nature of quantities

Module 3 – Forces and motion

3.1 Motion
3.2 Forces in action
3.3 Work, energy and power
You are here! 3.4 Materials
3.5 Newton's laws of motion and momentum

Module 4 – Electrons, waves and photons

4.1 Charge and current
4.2 Energy, power and resistance
4.3 Electrical circuits
4.4 Waves
4.5 Quantum physics

3.4 Materials

- 3.4.1 Springs
- 3.4.2 Mechanical Properties of Matter

3.4.1 Springs

3.4.1 Springs

	Learning outcomes
	Learners should be able to demonstrate and apply their knowledge and understanding of:
(a)	tensile and compressive deformation; extension and compression
(b)	Hooke's law
(c)	force constant k of a spring or wire; $F = kx$
(d)	(i) force–extension (or compression) graphs for springs and wires
	(ii) techniques and procedures used to investigate force–extension characteristics for arrangements which may include springs, rubber bands, polythene strips.

What is deformation?

Deformation of Materials

- Deformation = changing the shape of an object.
- In order for an object to be deformed, a pair of equal and opposite forces must be applied to it.
  - So, by definition whenever forces are applied to an object, the object is deformed.
    - Many deformations are not noticed.
    - Many deformations spring back once the force is removed.

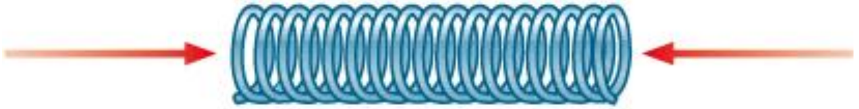
Types of Deformations

- Elastic deformations
  - Once the distorting force has been removed from a deformed object, the object springs back to its original form.
  - Most deformations are elastic.
- Plastic deformations
  - Once the distorting force has been removed from a deformed object, the object remains permanently deformed.

Tensile & Compressive Forces

- Tensile Forces
  - Equal and opposite forces causing extension in an object.
- Compressive Forces
  - Equal and opposite forces causing compression of an object.

Tension describes the pulling forces exerted by the wire towards its centre.

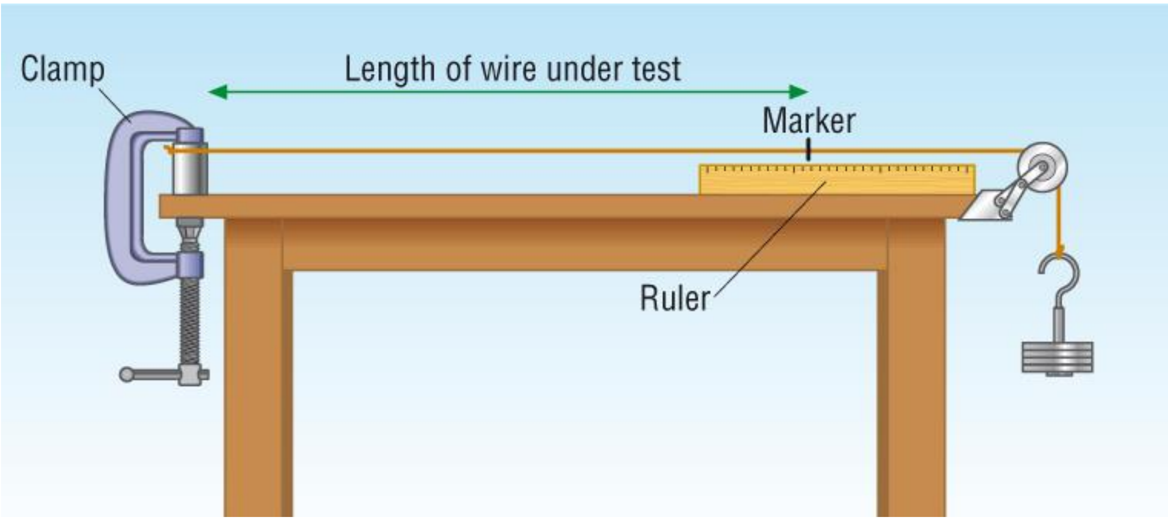


Compression describes the pushing forces exerted by the wire away from its centre.

Tension and compression are not forces themselves, they are both due to electromagnetic potential energy gains as atoms are pulled apart or pushed together.

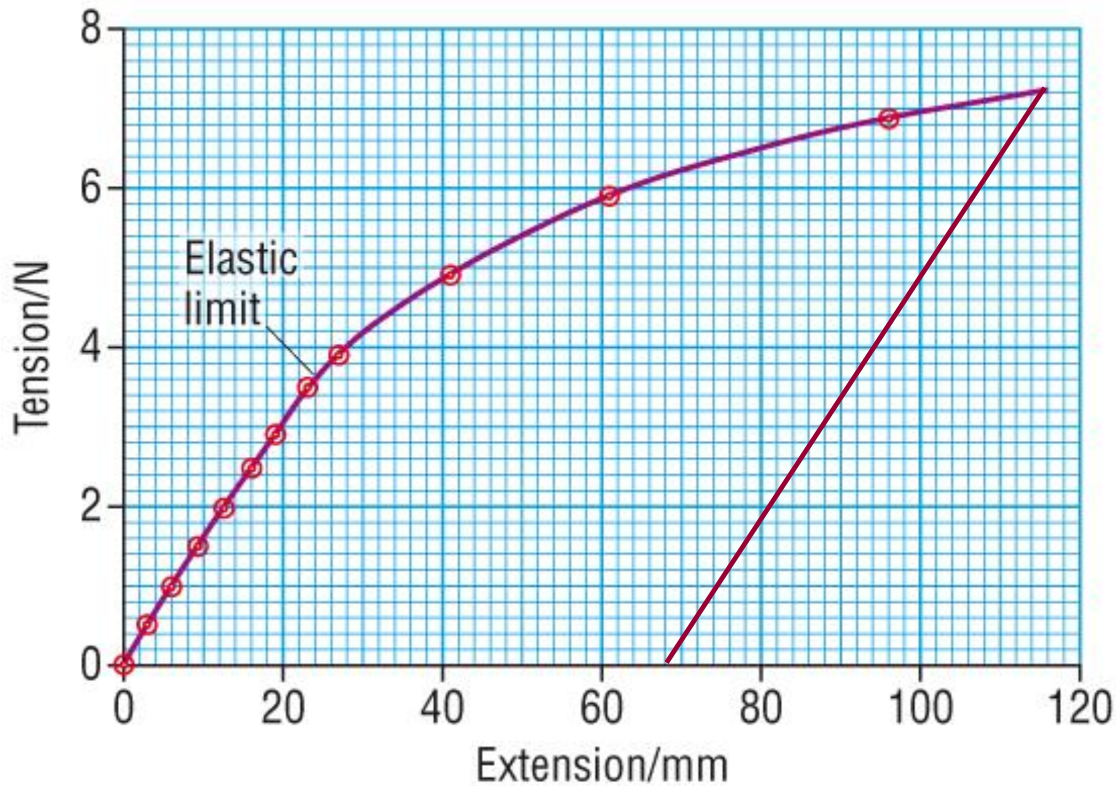
An investigation to stretch a wire

- Set up the apparatus as shown below.
- Plot extension against tension with extension on the x axis.
- BEFORE the wire snaps, begin removing masses and continue to plot the extensions.
- Summarise your findings.

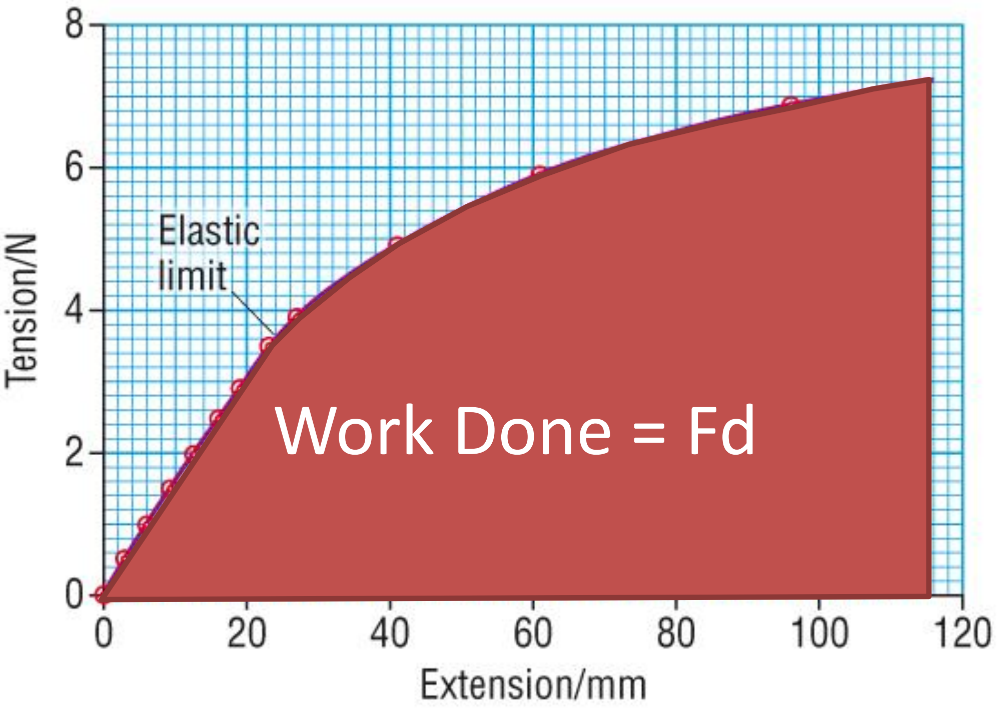


What should you have seen?

- The graph shows two regions:
  - Straight line with F<4N.
  - Curved line with F>4N.
- The elastic limit shows the end of proportionality, where below this limit the wire will act elastically.
- Above this limit the wire acts plastically and the deformation is permanent.
- Did you notice any creep in your extension values with high tensions?
- As masses are removed the wire fails to return to original length if the elastic limit has been exceeded.



Extension is plotted on the x axis?



- When we plot graphs, the independent variable goes on the x axis.
- If we look at the area under this curve we see it is equal to Force x Distance, otherwise the Work Done in extending the wire.

What is the relationship between force and extension?

Hooke’s Law

- **The extension of an elastic body is proportional to the force which causes it.**
- We saw this in our wire example before the elastic limit was reached.
- With elastic extension, force is proportional to extension:

$$F \propto x \qquad \text{Or...} \qquad F = kx$$

Where k is the force constant

Hooke's Law Equation

$$F = kx$$

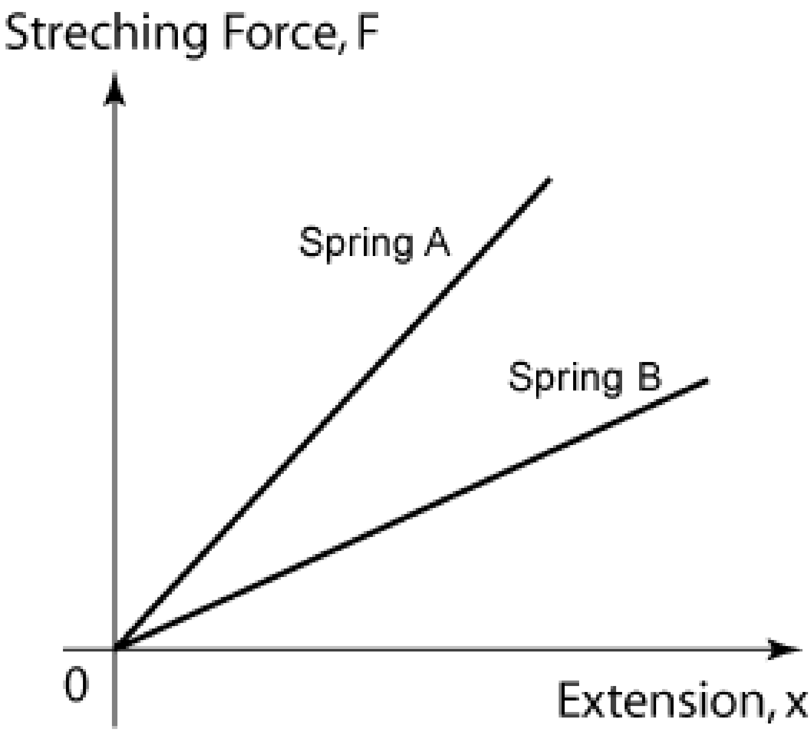
- Where:
  - F is the force producing the extension.
  - x is the extension.
  - k is the force constant (or spring constant)

- The force constant is measured in Nm^{-1}. It tells us how much force is needed for a 1 metre extension.
  - Also tells us the stiffness of the spring.
- **This equation only applies to elastic deformations.**

Force Constant, k

- Can be used to describe the stiffness of a spring.
- Can be found from the gradient of a force-extension graph.

- Describe these two springs:



Other uses of Hooke’s Law

- F=kx is not just used to describe the extension of springs:
  - Can be used to describe:
    - Compressions as well as extensions
    - Atom behaviour in solids
    - Wires/girders under tension or compression

    - Anything which can be squashed/extended elastically.

Investigating Hooke's Law

- Measure the spring constant of:
  - A single spring
  - Two similar springs in series
  - Two similar springs in parallel

- Compare the stiffness of the three spring arrangements.

3.4.1 Springs (review)

3.4.1 Springs

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) tensile and compressive deformation; extension and compression

(b) Hooke's law

(c) force constant *k* of a spring or wire; $F = kx$

(d) (i) force–extension (or compression) graphs for springs and wires

(ii) techniques and procedures used to investigate force–extension characteristics for arrangements which may include springs, rubber bands, polythene strips.

3.4.2 Mechanical Properties of Matter

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Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) force–extension (or compression) graph; work done is area under graph

(b) elastic potential energy; $E = \frac{1}{2}Fx$; $E = \frac{1}{2}kx^2$

(c) stress, strain and ultimate tensile strength

(d) (i) Young modulus = $\frac{\text{tensile stress}}{\text{tensile strain}}$, $E = \frac{\sigma}{\varepsilon}$

(ii) techniques and procedures used to determine the Young modulus for a metal

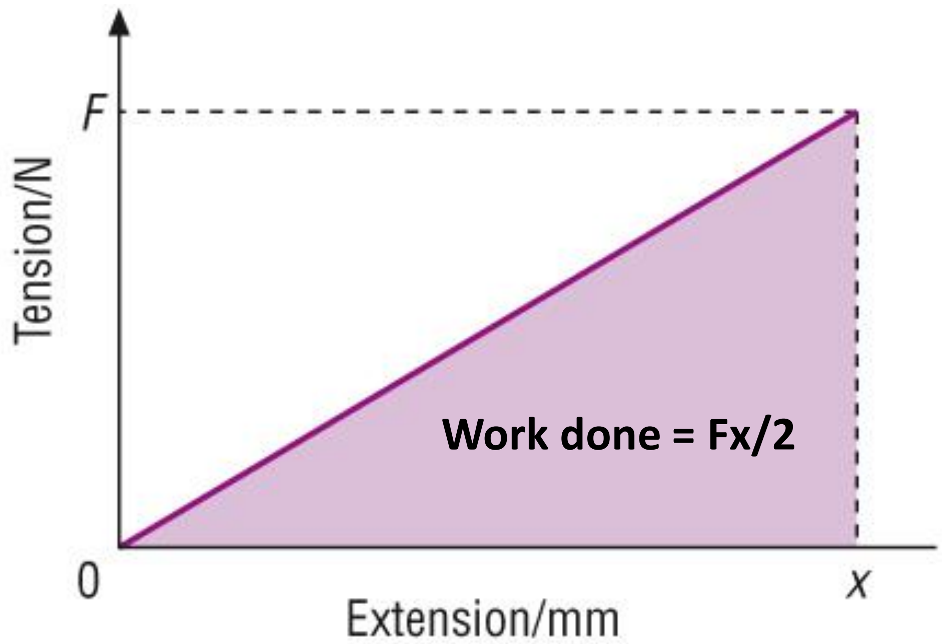
(e) stress–strain graphs for typical ductile, brittle and polymeric materials

(f) elastic and plastic deformations of materials.

What happens to the work done on a spring?

Work Done to stretch a spring

- Work done = Fd.
- However, since the force required to stretch the spring is not constant, F gradually increases with extension.
- So the equation becomes
  - Work = Fx/2
- Since F=kx, the equation can also be written as
  - Work = $kx^2/2$



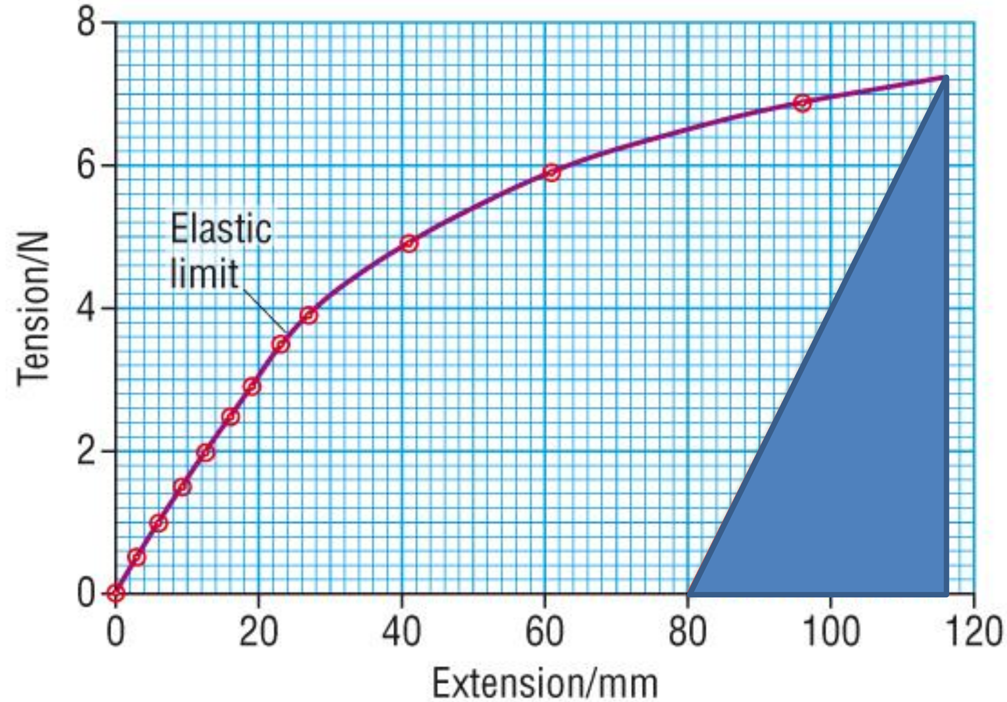
Elastic Potential Energy

- Since work has been done on a spring to stretch it, the energy is stored as elastic potential energy in the spring.

- Many toys/clocks/etc use springs to store energy which is released as the item is used.

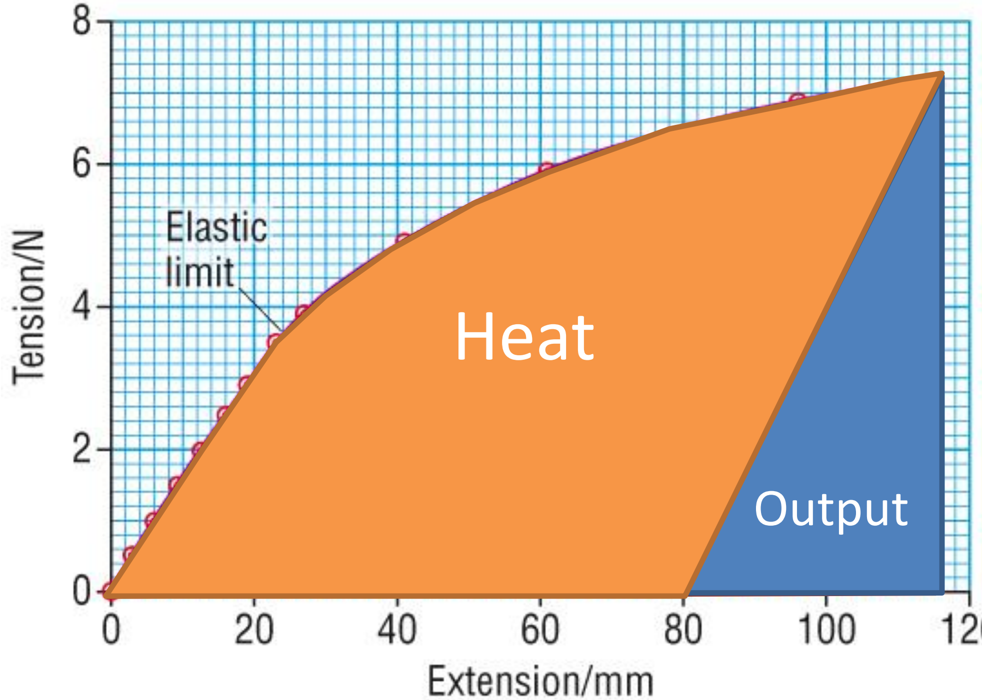
$$E = \frac{1}{2}Fx = \frac{1}{2}kx^2$$

What would happen to the extension if we removed the masses now?



- Since we have passed the elastic limit, the wire will not go back to its original length.
  - However, it will reduce its length a bit.
- The area under this line represents the energy released by the wire.

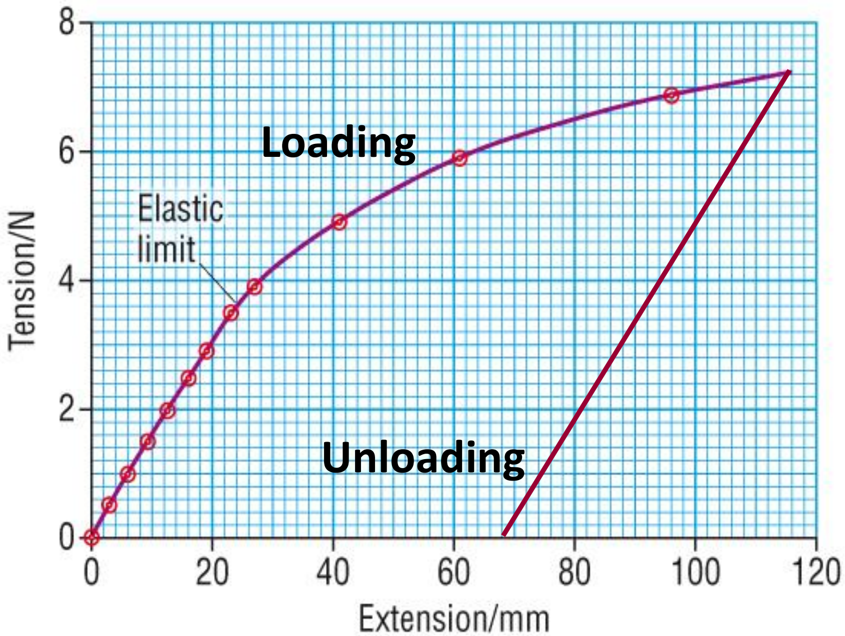
So what happens to the rest of the energy?



- We have added energy to the wire to extend it.
- Some of this energy is released from the wire as it relaxes.
- The rest of the energy causes the wire to become heated.

Loading and Unloading

- Different materials respond differently to being stretched/compressed.
- This causes their Force-Extension curves to have different shapes.
- Often the loading curve (the F-E curve as force is being applied to a material) is different from the unloading curve (the F-E curve as force is released from a material).

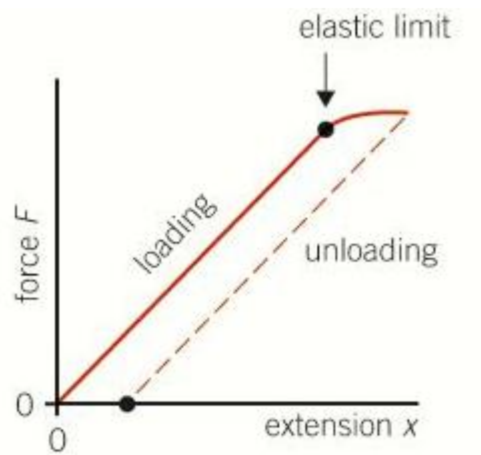


Using loading curves to identify materials

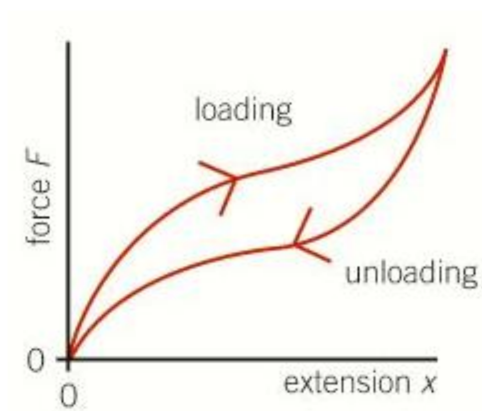
- The shape of loading/unloading curves can help us identify a material.

What type of material could these be showing?

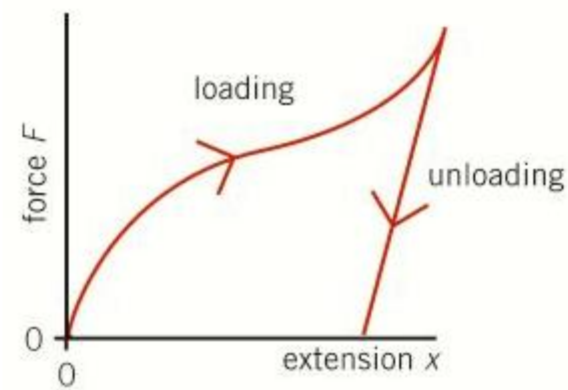
Describe each graph in detail



Metal wire/spring



Rubber band



Polythene bag

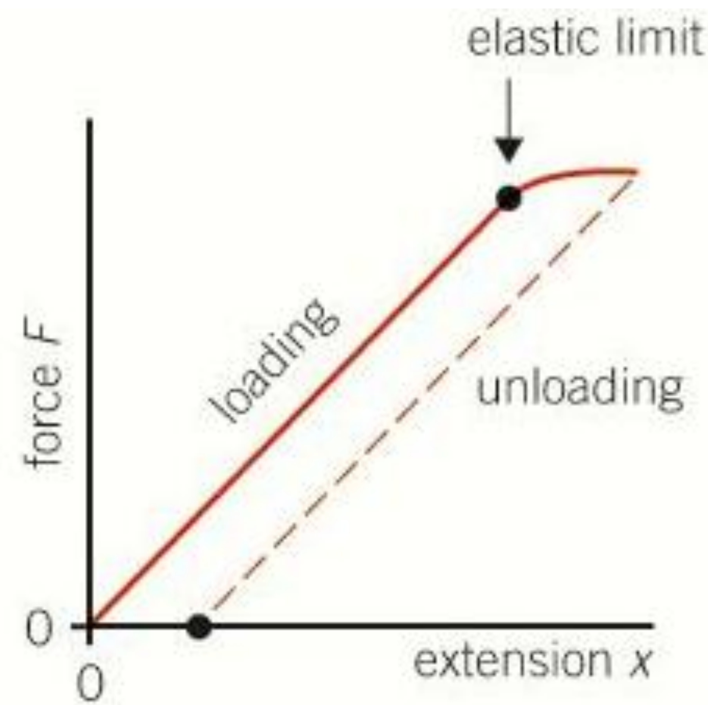
They could either be:

- Polythene bag
- Metal spring
- Rubber band

Detailed descriptions:

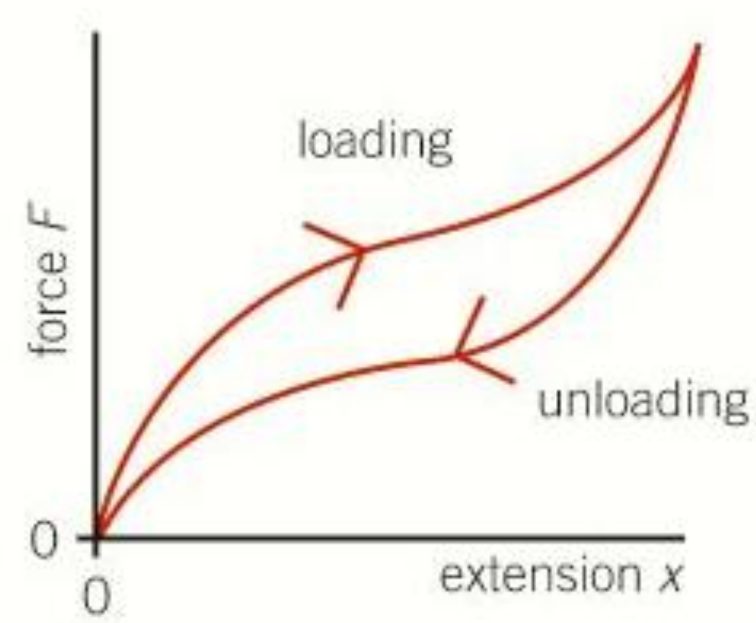
- Is Hooke's law obeyed?
- Is the extension elastic or plastic?
- What happens during unloading?

Metal wire/spring



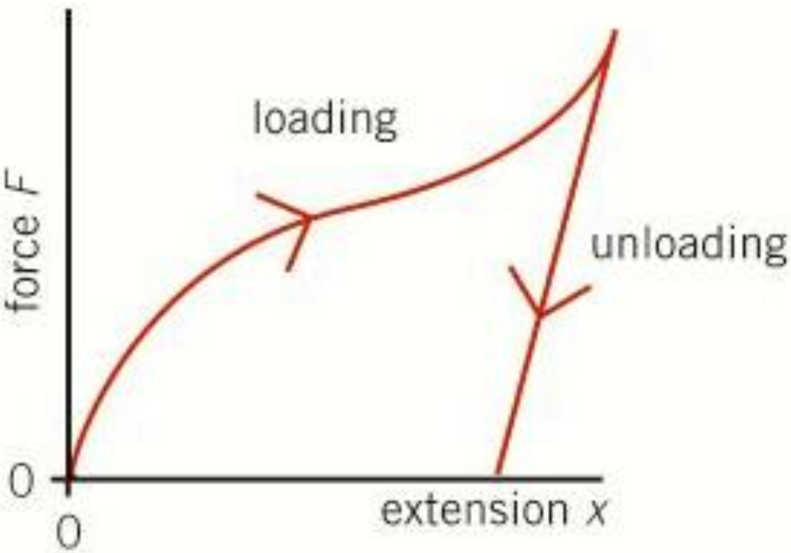
- Loading follow Hooke's law until the elastic limit is reached.
- Below this limit, unloading will follow the loading line.
- Above the limit unloading is parallel to but offset from loading due to the permanent plastic extension.
- After unloading the material is longer than it was originally – it has suffered plastic deformation.

Rubber band



- Loading does not obey Hooke's law.
- Deformation is elastic but loading and unloading curves are different.
- More work is done stretching the rubber than is done when it is released – this extra work is released as thermal energy.
- The loop shape to the two curves is called a hysteresis loop.

Polythene bag



- Loading does not obey Hooke's law.
- Suffers plastic deformation with even a small force.

All this stress is causing me a real strain. What does this mean?

Stress v Strain

- These words are used everyday but in physics they mean something specific.

- Stress, σ
  - A force per unit cross sectional area applied to a solid object.
  - Units are Nm^{-2} (same as pressure but pressure applies to liquids & gases) (also called Pascal, Pa)
- Strain, ε
  - Extension per unit length of a solid object.
  - Strain is unitless (since it is a length/length)
  - Strain is often quoted as a percentage (3%=0.03)
    - The object has extended by 3cm for every metre of original length.

Example

- Stress causes strain.
- How much strain is caused depends on the stiffness of the object.

- With a stiff material like iron a large stress will only produce a small strain.
- But with a soft material like rubber a small stress is enough to produce a large strain.

The Young Modulus

- The ratio between stress and strain in a material, **within the limit of proportionality**.
- The Young Modulus (Y) = Stress/Strain
- Stiff materials have a higher Y than soft materials.

diamond	12×10^{11}
iron	2.1×10^{11}
copper	1.2×10^{11}
aluminium	0.71×10^{11}
lead	0.18×10^{11}
rubber	0.0002×10^{11}

Table 1 Young modulus for some common materials/Pa.

The Young Modulus

- Since:
  - Stress = force/area (F/A)
  - Strain = extension/length (x/l)

$$Y = \frac{Stress, \sigma}{Strain, \varepsilon}$$

- Y can also be written as:

$$Y = {\frac{Force}{Area}} \Big/ {\frac{Extension}{Length}} \quad \text{or} \quad Y = \frac{Force \times Length}{Area \times Extension}$$

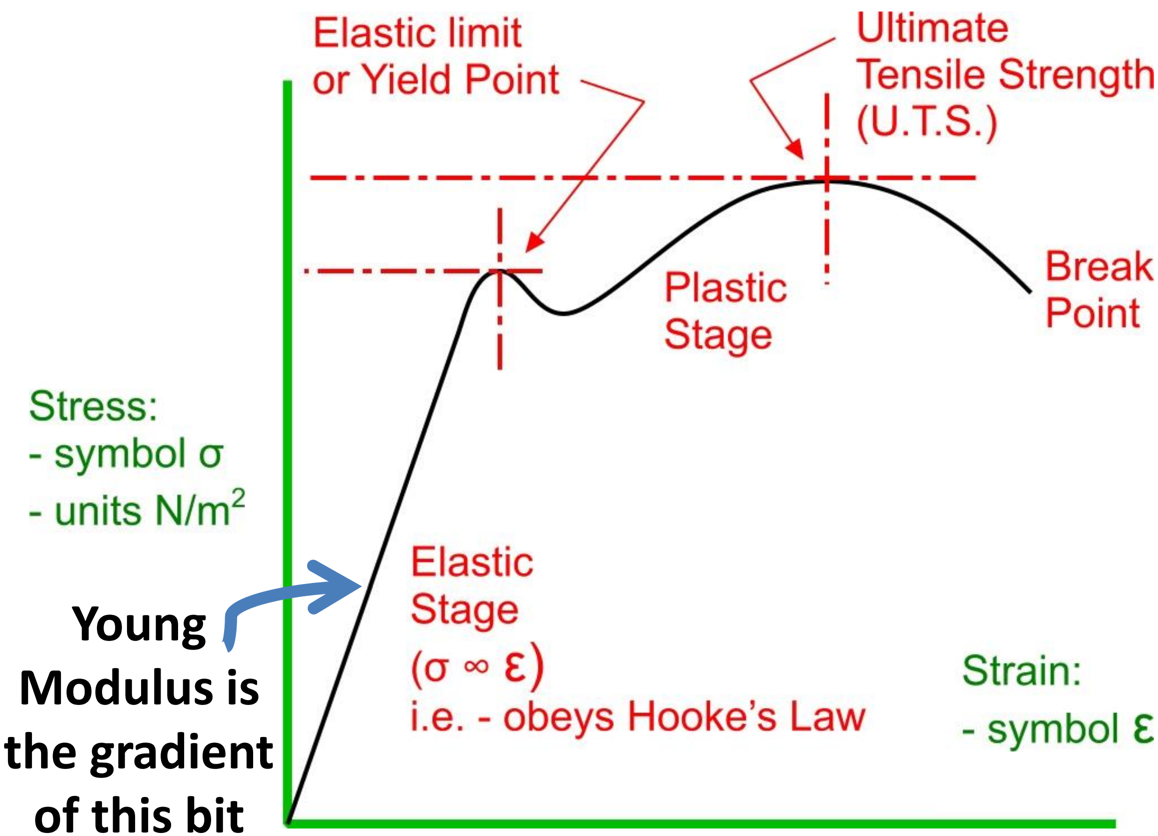
Uncertainty of Measurement

- When calculating a Young Modulus for a material, uncertainty can come from:
  - Difficulty accurately measuring the extension of the material.
  - Difficulty measuring the cross sectional area.
- What can be done about these?
  - A travelling microscope can measure extension to the nearest 0.01mm.
  - For manufactured wires, the company making them specify the cross sectional area using a swg (standard wire guage) rating. This saves us from having to measure its diameter and squaring it to gain the area.

Material Choices

- With any manufacturing, the choice of material to use depends on a number of properties, including:
  - Ductility
  - Brittleness
  - Stiffness
  - Density
  - Elasticity
  - Plasticity
  - Toughness
  - Conductivity
  - Cost
  - Ease of shaping
  - Customer appeal

Some of these properties can be shown on a stress v strain graph

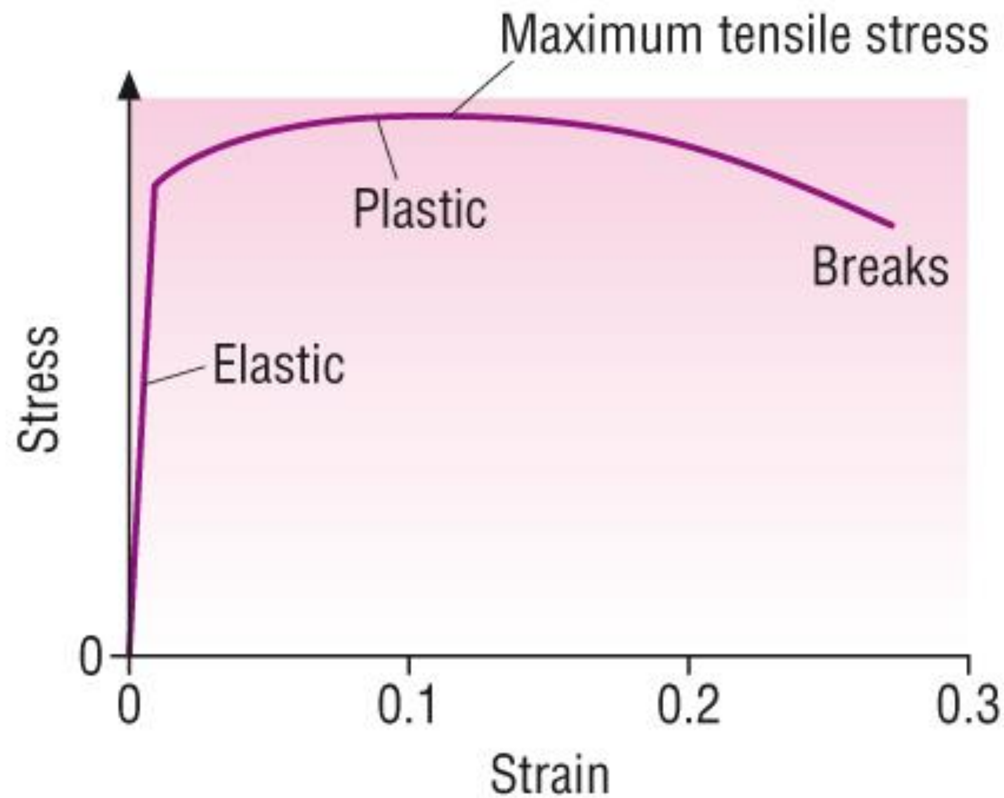


- EL/YP – the point beyond which the material is no longer elastic.
- UTS – the largest stress which the material will withstand before breaking

A strong material has a high UTS

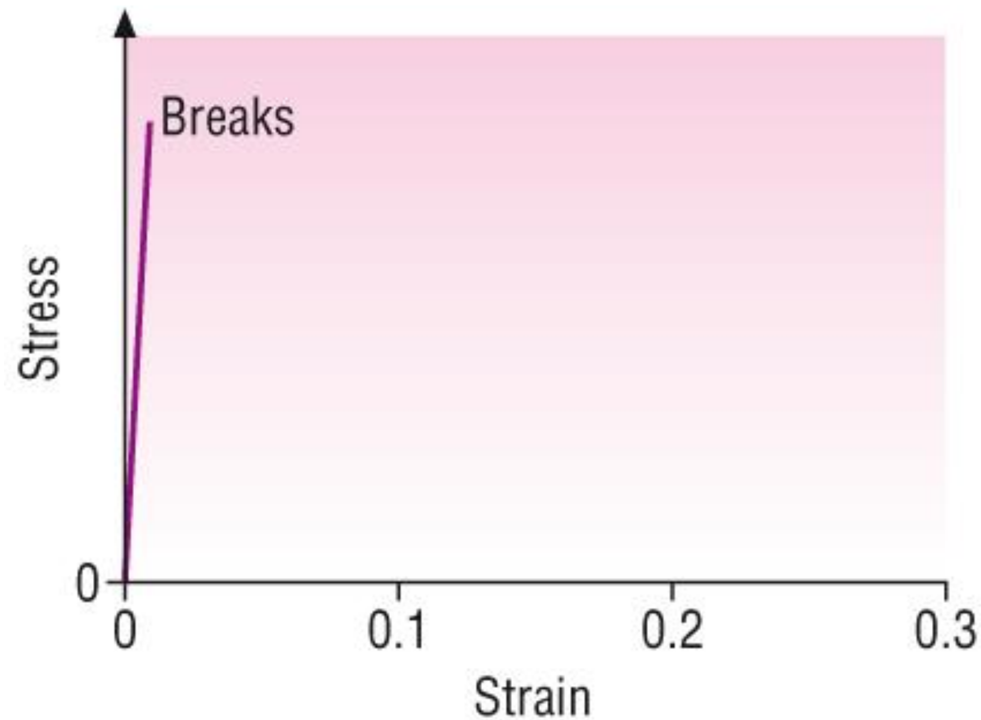
Ductile Materials (most metals)

- Large plastic region.
  - Material continues to stretch even if stress is reduced.
  - As the wire extends, its cross sectional area decreases, leading to increased stress with no increased force.



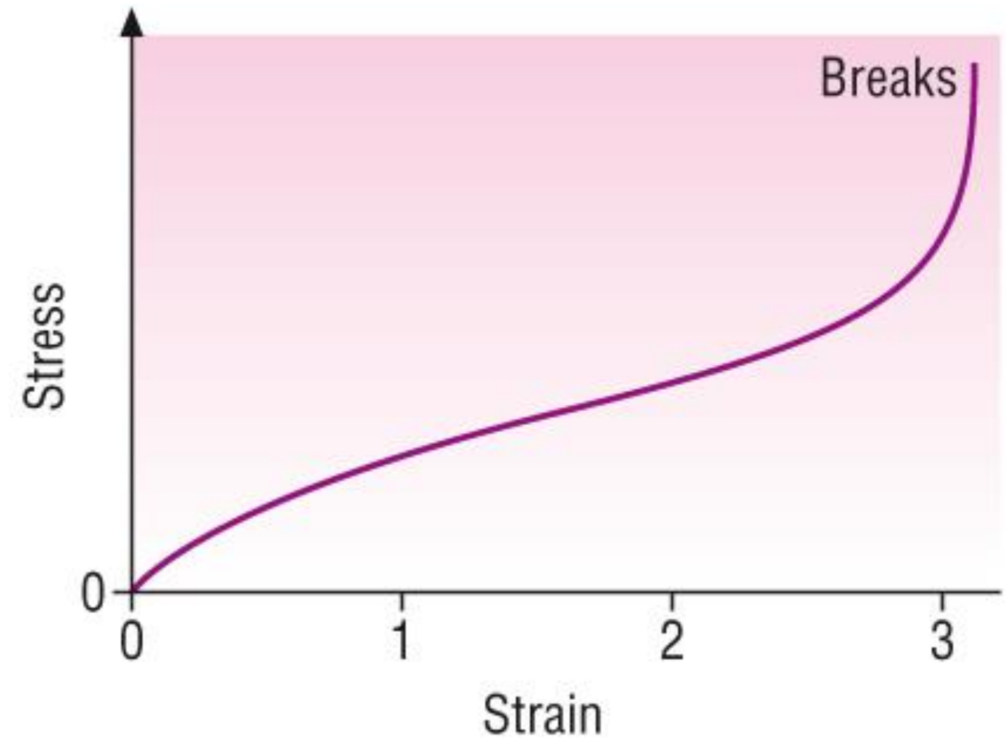
Brittle Materials

- Very little deformation before the material breaks.
- Small area under the graph shows little elastic potential energy is stored by the material.



Polymeric Materials

- Large degree of strain. For a given stress (compare scales on previous slides)
- Eg. Rubber can easily extend 4 times its original length.
  - Due to molecules being tangled long chains which straighten as stress is applied.



Note the high values of strain

3.4.2 Mechanical Properties of Matter (review)

3.4.2 Mechanical properties of matter

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Complete!

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